

ARMY RESEARCH LABORATORY



# Polymeric Material Study for the D-Fuze Windshield

Michael S.L. Hollis

ARL-MR-525

JANUARY 2002

20020201 051

Approved for public release; distribution is unlimited.

Cycolac® and Ultem® are registered trademarks of G.E. Plastics.

Nylatron® is a registered trademark with DSM Engineering Plastic Products.

PEEK™ is a trademark of Victrex PLC-United Kingdom.

Series IX™ is a trademark of Instron Corporation.

Stycast® is a registered trademark of Emerson and Cumings, Inc.

Victrex® is a registered trademark of Victrex PLC Corporation - United Kingdom.

Zytel® is a registered trademark of E.I. DuPont de Nemours & Co., Inc.

The findings in this report are not to be construed as an official Department of the Army position  
unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of  
the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

**Army Research Laboratory**  
Aberdeen Proving Ground, MD 21005-5066

---

ARL-MR-525

January 2002

---

# Polymeric Material Study for the D-Fuze Windshield

Michael S.L. Hollis  
Weapons and Materials Research Directorate

---

Approved for public release; distribution is unlimited.

---

---

## Abstract

---

Pursuant to a previous report [1], an effort has been made to continue to find higher performance materials for the design of windshields. A product that the U.S. Army Research Laboratory provides the test and evaluation community is a yawsonde, now termed "diagnostic fuze" or "D-fuze". This device is capable of sensing the inertial environment of a cannon-launched projectile and telemetering the live data to a ground station. In order to telemeter data in flight, the antenna has to radiate through a protective windshield. This windshield is not only transparent to radio frequency radiation but is also a means of ballistic and thermal protection.

A recent flight experiment with a prototype artillery projectile revealed a weakness of the nylon 66 windshields to "blow-by"<sup>1</sup> gases. The windshields were designed to survive aero-pressures attributable to Mach 3 launch and flight with a significant safety factor. However, blow-by effects were never considered.

A cursory study has been performed on selected extruded bar stock polymers, which are readily available without our having to consult a compounding source, for machining windshields for D-fuzes of various geometries. Ultem® 2300 appears to provide the best mechanical, thermal, and electrical properties of the studied polymer materials. However, depending on the thickness of the geometry, a designer may want to reconsider using unfilled Ultem® 1000. The cross section of the geometry reduces to a range near 0.03125 inch; there may not be enough glass fiber to reinforce the polyetherimide matrix. Further literature research indicated that the ogive of the M762 fuze is made from injected molded polyetherimide with 30% glass filler.

---

<sup>1</sup>Propulsion gases that leak past the projectile's obturator. In addition to the air already being pushed by the launching projectile, these gases increase the total pressure on the windshield.

## ACKNOWLEDGMENTS

The author would like to recognize the following personnel of the U.S. Army Research Laboratory who probably should have more credit in this report than a mere acknowledgment. These people are lauded for their expertise, knowledge, effort, and team spirit. Mr. John Condon is acknowledged for continuing the design and fabrication of windshields. Charlie Mitchell was critical in providing support. Paul Moy, Tom Mulkern, and Dr Steve McKnight were extremely crucial as resources, references, and verifiers. Finally, Robert Kaste is recognized for his expertise in structural analysis.

INTENTIONALLY LEFT BLANK

---

## Contents

---

|     |  |    |
|-----|--|----|
| 1.  | Introduction .....   | 1  |
| 2.  | Background .....   | 2  |
| 3.  | Experiment .....   | 4  |
| 3.1 | Windshield Crush Experiments .....   | 4  |
| 3.2 | Three-Point Bending Experiments .....  | 6  |
| 4.  | Conclusion .....   | 7  |
| 5.  | Future Work .....  | 8  |
|     | References .....   | 9  |
|     | Bibliography .....   | 11 |
|     | Appendix   |    |
| A.  | Stycast® 1090 SI Electro-mechanical Properties Verification .....            | 13 |
|     | Distribution List .....  | 17 |
|     | Report Documentation Page .....  | 23 |
|     | Figures  |    |
| 1.  | Schematic of a D-Fuze .....  | 1  |
| 2.  | Schematic of a D-Fuze Windshield .....                                       | 2  |
| 3.  | Linear Force Deflection Range of Nylon 66 Windshield Crush Experiments ..... | 5  |
| 4.  | Radome Crush Experiment Results .....  | 6  |
|     | Tables   |    |
| 1.  | Material Properties of Studied Polymers .....                                | 3  |
| 2.  | Flexural Bending Experimental Results .....                                  | 7  |

INTENTIONALLY LEFT BLANK

## 1. Introduction

---

Pursuant to an earlier U.S. Army Research Laboratory (ARL) report [1], an effort has been made to find higher performance materials for the design of windshields. A product that ARL provides to the test and evaluation community is a yawsonde, which is now termed "diagnostic fuze" or "D-fuze". This device is capable of sensing the inertial environment of a cannon-launched projectile and telemetering the live data to a ground station. This device, as seen in Figure 1, is normally screwed onto an artillery shell.

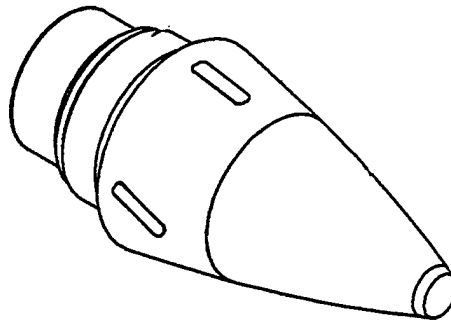


Figure 1. Schematic of a D-Fuze.

In order to telemeter data in flight, the antenna has to radiate through a protective windshield. This windshield is not only transparent to radio frequency radiation but is also a means of ballistic and thermal protection. Figure 2 shows the geometry of the windshield.

A recent flight experiment with a prototype artillery projectile revealed a weakness of the nylon 66 windshields to "blow-by"<sup>1</sup> gases.

The windshields were designed to survive aero-pressures attributable to Mach 3 launch and flight with a significant safety factor. However, blow-by effects were never considered. Previous analysis indicated that the windshield should survive 1000 psi for these effects. This analysis used standard material properties based on certain American Society for Testing Materials (ASTM) standards: ASTM D638 for tensile modulus and D790 for flexural modulus. However, the flight experiment indicated differently. This prompted an investigation into the actual

---

<sup>1</sup>Propulsion gases that leak past the projectile's obturator. In addition to the air already being pushed by the launching projectile, these gases increase the total pressure on the windshield.

properties of the nylon 66. This report covers the various material experiments to determine a new material for the D-fuze windshield.

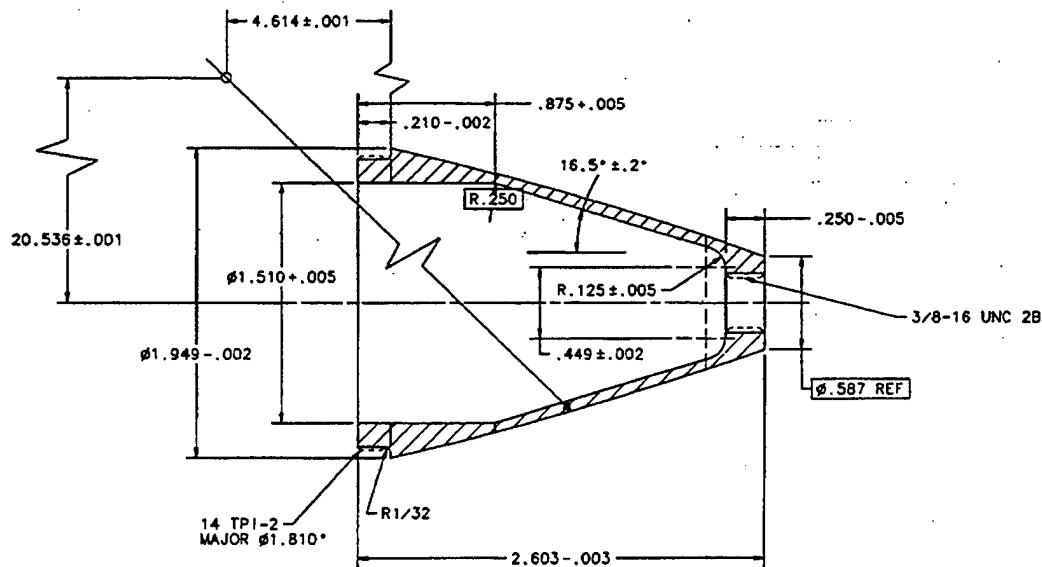


Figure 2. Schematic of a D-Fuze Windshield.

---

## 2. Background

---

Table 1 displays the material properties of various materials used in this study. These materials specifically are

- Nylon 66, which is unfilled. This semi-crystalline material is very common with a variety of manufacturers.
- Nylatron® GSM Blue contains finely distributed particles of molybdenum disulphide to enhance its bearing and wear behavior without impairing the impact and fatigue resistance inherent in unmodified cast nylon grades ([http://www.dsmepp.com/products/europe/nylons\\_europe.html#nytrgsm](http://www.dsmepp.com/products/europe/nylons_europe.html#nytrgsm)).
- Unfilled polycarbonate is a thermoplastic resin that is very common with a variety of manufacturers such as General Electric or Bayer.
- Cycolac® acrylonitrile butadiene styrene (ABS) is an unfilled thermoplastic consisting of (poly)ABS.
- Zytel® ST801HS is an unfilled heat-stabilized toughened nylon.

- Ultem® 1000, an unfilled amorphous polyetherimide, is manufactured by General Electric Plastics.

- Ultem® 2300 is an amorphous polyetherimide, with 30% glass reinforcement.

- Victrex® polyetheretherketone (PEEK™), with 40% glass fiber reinforcement, is a polyetheretherketone, glass-reinforced, semi-crystalline polymer.

- Polyimide has 40% glass fiber reinforcement. This particular combination is available at RTP company.

Table 1. Material Properties of Studied Polymers

|   | Nylon<br>6/6 | Nyla-<br>tron®<br>GSM<br>Blue | Poly-<br>carbo-<br>nate<br>Unfilled | Cycolac®<br>AR ABS | Zytel®<br>ST801HS | Ultem®<br>1000 | Ultem®<br>2300 | PEEK™<br>40% long<br>glass<br>fiber | Polyi-<br>mide<br>40% glass<br>fiber |
|---|--------------|-------------------------------|-------------------------------------|--------------------|-------------------|----------------|----------------|-------------------------------------|--------------------------------------|
| Property                                      |              |                               |                                     |                    |                   |                |                |                                     |                                      |
| Specific Gravity                              | 1.15         | 1.15                          | 1.28                                | 1.04               | 1.15              | 1.28           | 1.51           | 1.62                                | 1.63                                 |
| Flexural Modulus of Elasticity (psi)          | 450,000      | 500,000                       | 350,000                             | 345,000            | 150,000*          | 500,000        | 800,000        | 2,000,000                           | 1,750,000                            |
| Flexural Strength (psi)                       | 15,000       | 15,000                        | 13,000                              | 11,748             | N/a               | 20,000         | 30,000         | 40,000                              | 41,000                               |
| Heat Deflection Temperature 264 psi (F)       | 200          | N/A                           | 290                                 | 172                | 158               | 392            | 410            | >500                                | 630                                  |
| Tg-Glass Transition (amorphous) (F)           | N/A          | N/A                           | 293                                 | N/A                | N/A               | 419            | 419            | N/A                                 | N/A                                  |
| Melting Point (crystalline) (F)               | 500          | 520                           | N/A                                 | N/A                | 500               | N/A            | N/A            | N/A                                 | N/A                                  |
| Water Absorption Immersion, 24 hours % by wt. | 0.3          | .22                           | .2                                  | N/A                | N/A               | 0.25           | 0.18           | 0.1                                 | 0.08                                 |
| Dielectric constant, 106 Hz                   | 3.6          | N/A                           | 3.17                                | N/A                | N/A               | 3.15           | 3.7            | N/A                                 | 3.6                                  |

Materials such as Nylatron®, polycarbonate, Zytel®, and cycolac® were previously used in windshield fabrication. These materials were thought to be less durable to launch stress or to aero-dynamic heating. An early drawing schematic of an injection molded windshield, dated 1972, required Zytel®, which is a modified nylon. Other early windshield designs required injection molded cycolac®. Apparently, because of low volume production runs and the costs of molds, injection molding was discarded, and fabrication of the windshields required machining from previously extruded or cast bar stock material. Current fabrication is based on available bar stock material. Based on this, PEEK™ and polyimide, both with 40% glass, were eliminated because they were too expensive for distributors to stock.

In addition to mechanical, electrical, and thermal properties, water absorption was examined. The asterisk (\*) on the Zytel® flexural modulus of elasticity indicates that this quantity was measured in 50% relative humidity. With less water absorption (0.2% moisture content by weight), mechanical properties improve significantly. The flexural modulus is on the order of 250,000 psi.

---

### 3. Experiment

---

#### 3.1 Windshield Crush Experiments

Experiments consisted of crushing windshields of very similar geometries, yet different materials. In addition, three-point flexural investigation of Ultem® 1000 and 2300 material was performed as a verification. Crushing was performed with an Instron 4505 frame. The windshield was placed between the platens, and the cross-head speed was set for 0.05 in./min. Data were acquired with Series IX™ software.

Several nylon 66 windshields were crushed to determine repeatability of the experiment. Figure 3 shows the linear regions of those experiments.

Two experiments used windshields from an old fabrication run, and the other two came from a newer run. No significant difference was observed, so all the plots were averaged. Data from the average curve were used to calibrate a finite element analysis (FEA) of the nylon 66 windshield. The modulus of elasticity was adjusted until the model results correlated with the linear crush experiment average results. The FEA indicated that the nylon 66, which has a modulus of 450,000 psi, based on ASTM 790 standard, had a reduced modulus of 260,000 psi. The reason for this is because of the moisture absorption of nylon 66. Water degrades the strength of nylon 66 by interfering with the hydrogen bonds of the polymer (personal communications, Steve McKnight, ARL, April 2001). In addition, the moisture causes swelling of the material, which makes it difficult to

maintain dimensional tolerances. The hygroscopicity of the nylon 66 caused the windshields to absorb moisture within days. During fabrication runs, the windshields fit the aluminum nacelles and passed the acceptance check. Yet, when a D-fuze was assembled, the parts no longer fit together, requiring effort of the assembler to screw the windshield onto the nacelle.

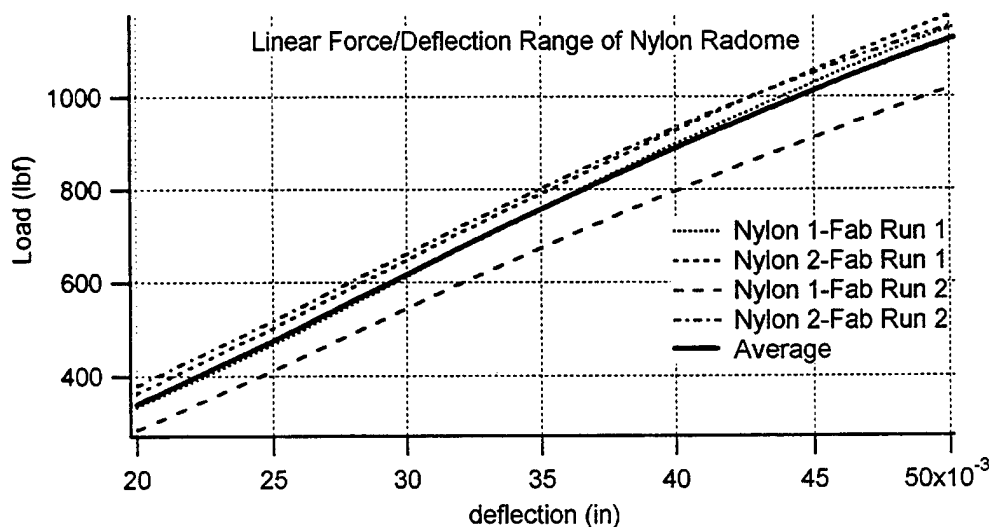


Figure 3. Linear Force Deflection Range of Nylon 66 Windshield Crush Experiments.

Based on the newer modulus, the amount of blow-by pressure that the nylon 66 windshield could survive was 750 psi. The need for a new windshield design became apparent. However, packaging design constraints dictate that the geometry could not change significantly. What was needed was a material change and a manufacturing change.

Several polymers were considered to replace nylon 66. Most of these materials were not readily available in cylinder stock but were available in pellet form for use in injection molding. The injection molding of the windshield with glass-filled resins could provide an improvement in mechanical properties. This process would orient the glass fibers in the axial direction of the windshield, allowing for more strength against buckling (personal communications, Thomas Mulkern, ARL, April 2001). However, because of the limited quantity of the fabrication runs, injection molding was too expensive. The one material in this study that was readily available in cylinder stock was Ultem® 2300. A quick fabrication run of the windshield design with this material was performed. As one can see in Figure 4, the nylon 66 did not fare as well as the other materials. The newer material, Ultem® 2300, did extremely well.

Based on Figure 4, one can see a drastic improvement in the strength of the windshield. The new windshields were assembled with the D-fuzes and were fired in the same type of flight experiment in which the nylon 66 windshields failed. The amount of blow-by pressure from both series of experiments has not been quantified, but the Ultem® 2300 windshields survived.

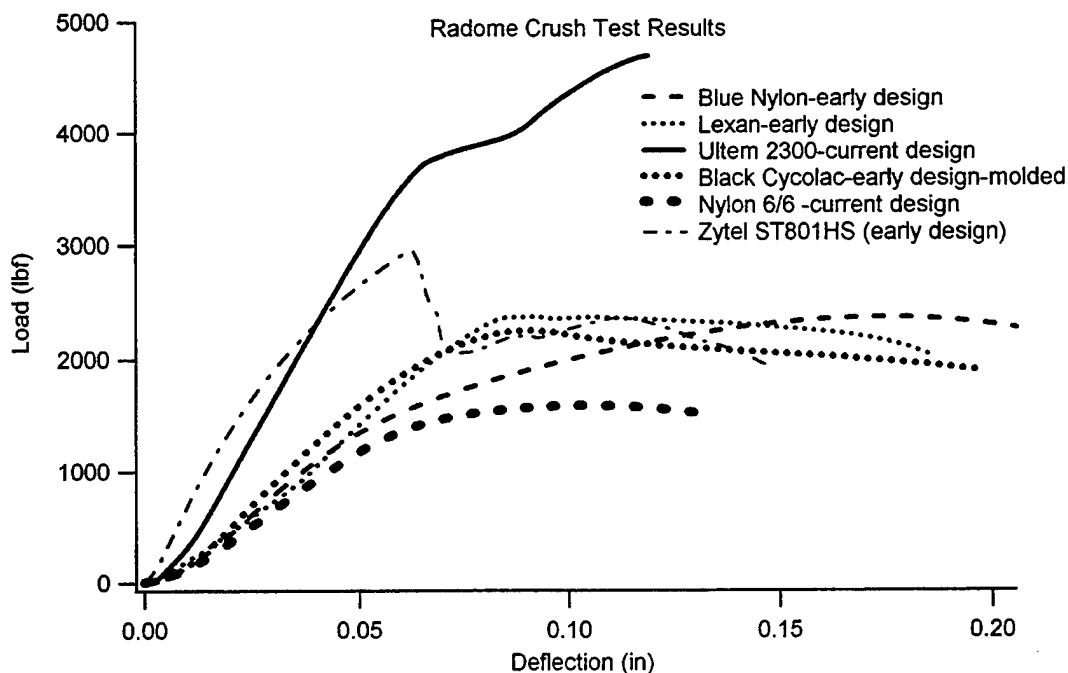


Figure 4. Radome Crush Experiment Results.

### 3.2 Three-Point Bending Experiments

As a verification, three-point bending experiments were performed on Ultem® 1000 and 2300 to verify the actual flexural modulus of elasticity of the specific stock from which parts were being made. Early cross-referencing of various data sheets for Ultem® 2300 indicated a significantly varying flexural modulus, even though the same standard (ASTM D790) was used. Since Ultem® 2300 contains 30% glass fibers, this report surmised that the thinner the specimen became, the less glass content in the matrix; therefore, at some thickness, the glass-filled resin should behave like the unfilled resin. Each experiment contained four or five evaluated specimens. Table 2 displays the results of the experiments.

All these specimens were taken from the same piece of 2-inch bar stock. Also, the specimens were cut from a 1- by 1-inch area in the center of the stock. Specimens were also cut lengthwise with respect to the axis of the bar stock. As one can see, the variation in flexural modulus of elasticity between the 0.125- and 0.0625-inch specimens would indicate a non-uniformity with which the fibers are dispersed. The interior region was initially chosen for specimen harvest because the fiber orientation was thought to be more random as opposed to being aligned axially

nearer the surface of the extruded stock. An average of the two moduli would be 814,500 psi, which is very close to what the specification sheet indicates.

Table 2. Flexural Bending Experimental Results

|                                      | Ultem® 2300<br>0.125 in. thick | Ultem® 2300<br>0.0625 in. thick | Ultem® 2300<br>0.03125 in. thick | Ultem® 1000<br>0.0625 in. thick | Ultem® 1000<br>0.03125 in. thick |
|--------------------------------------|--------------------------------|---------------------------------|----------------------------------|---------------------------------|----------------------------------|
| Average properties                   |                                |                                 |                                  |                                 |                                  |
| Displacement at Yield (in.)          | 0.300                          | 0.132                           | 0.100                            | 0.178                           | 0.109                            |
| Stress at yield (psi)                | 28,100                         | 36,400                          | 26,500                           | 31,300                          | 22,200                           |
| Strain at yield (in./in.)            | 0.056                          | 0.050                           | 0.075                            | 0.067                           | 0.081                            |
| Flexural Modulus of Elasticity (psi) | 670,000                        | 959,000                         | 486,000                          | 628,000                         | 343,000                          |

As the Ultem® 2300 specimen becomes thinner, the results show that the flexural modulus is the same as for unfilled Ultem® 1000. This may indicate that the fiber content in the sample is so low that the filled resin may as well be unfilled. The point of this is that if a design requires a certain thickness in the geometry, an unfilled resin may not be warranted specifically for Ultem®.

#### 4. Conclusion

A cursory study has been performed on selected extruded bar stock polymers, which are readily available for machining windshields for D-fuzes of various geometries. Ultem® 2300 appears to provide the best mechanical, thermal, and electrical properties of the studied polymer materials. However, depending on the thickness of the geometry, a designer may want to reconsider using unfilled Ultem® 1000. If the cross section of the geometry reduces to a range near 0.03125 inch, there may not be enough glass fiber to reinforce the polyetherimide matrix. Further literature research indicated that the ogive of the M762 fuze is made from injected molded polyetherimide with 30% glass filler.

---

## 5. Future Work

---

Another empirical means of validating the analyses, such as subjecting the windshields to a static pressure load until failure, should be performed. More intensive efforts to find higher performance material solutions for the design of windshields for future combat system-like projectile launch and flight conditions. Materials that have functional temperatures in the region of the adiabatic wall temperatures of supersonic and hypersonic vehicles need to be studied. Some of these materials may be ceramics, composites, and other polymers. Antenna radiation patterns and intensity measurements of the material and the geometry also need to be made. In addition, fabrication procedures should be studied. To achieve the best material properties from an engineered polymer, the parts should probably be injection molded rather than machined from a stock shape.

---

## References

---

1. Hollis, M.S.L., "Parameterized Design of a Supersonic Radome," ARL-TR-2418, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, April 2001.
2. Design News®, Reed Elsevier Properties, Inc., pp. 65-66, July 2, 2001.

INTENTIONALLY LEFT BLANK

---

## Bibliography

---

U.S. Army Research, Development, and Engineering Center, Drawing No. 12550981 "Ogive" note 1, Picatinny Arsenal, New Jersey.

DSM Engineering Plastic Products, Products and Applications Guide, Reading, PA, 2000.

Internet site, <http://www.matweb.com>.

Internet site, [http://www.dsmepp.com/products/europe/nylons\\_europe.html#nytrgsm](http://www.dsmepp.com/products/europe/nylons_europe.html#nytrgsm).

Internet site for GE Plastics-Cycolac AR ABS, <http://www.geplastics.com>.

Internet site, <http://www.dupont.com/enggpolymer/pdflit/americas/zytel/232409d.pdf>.

INTENTIONALLY LEFT BLANK

APPENDIX A

STYCAST® 1090 SI ELECTRO-MECHANICAL  
PROPERTIES VERIFICATION

INTENTIONALLY LEFT BLANK

## STYCAST® 1090 SI ELECTRO-MECHANICAL PROPERTIES VERIFICATION

Recently, the author was asked to look into the effects of moisture absorption on Stycast® 1090 SI. Stycast® 1090 SI is a low density, syntactic foam, epoxy encapsulant, which is commonly hardened with the 23LV catalyst. ARL frequently encapsulates electronics with Stycast®. The encapsulation, however, is not performed in desiccated laboratory conditions. There were concerns that the resin might be inherently hygroscopic or that moisture might enter during the mixture process, which could degrade electrical and/or mechanical properties. Even though the manufacturer (Emerson and Cumings) claims that the moisture absorption is negligible, simple electrical and mechanical property measurements were made to verify the manufacturing properties.

First, a determination of the dielectric constant and the loss tangent was made on a sample of cure Stycast®. The epoxy had been hardened for more than 24 hours at 25° C and 50% to 70% humidity. The experiment used a coaxial probe technique with a Hewlett-Packard 85070B measurement device. The dielectric measurement was from 0.2 GHz to 3 GHz. The dielectric constant ranged from 2.5 to 2.4 and the loss tangent averaged 0.033 for this range. The specification sheet has dielectric constants in increments: 60 Hz, 1 kHz, and 1 MHz, with the respective dielectric constants as 3.7, 3.1, and 2.9. The experimentation method for the specification sheet is ASTM D150. The downward trend indicates that the dielectric constant might be ~2.5 at 1 GHz, and this agrees with the specification sheet, even during the environmental conditions. The loss tangent averaged 0.01 to 0.02 for the same increments, which puts the results in close agreement with the specification sheet.

Second, a three-point bending experiment that employs ASTM D-790 standards was used to measure flexural stress and flexural modulus of elasticity. Specimens were created as per the ASTM requirements during 25° C and 50% to 70% humidity environmental conditions. Unfortunately, the specification sheet does not include the flexural modulus of elasticity. The manufacturer was queried for this property but they declined. The only property available to compare was the flexural strength. However, there were two values for this property of Stycast® 1090, with the 23LV catalyst. Again, the manufacturer was queried, but no response has been made. The two values listed for flexural strength are 4000 psi (28 MPa) and 6900 psi (48 MPa). The experiment used seven samples, of which, the average flexural strength was 7070 psi (49 MPa). Based on both specifications, the Stycast® does not appear to lose any strength.

In conclusion, Stycast® 1090 SI appears to maintain the manufacturer's specifications for dielectric constant, loss tangent, and flexural strength under fluctuating temperature and humidity. Since "...most materials today are tested at 1 MHz,...there is still a lot of uncertainty about how materials perform at

2.4 GHz" [2]. The electrical experiment verifies the dielectric properties of Stycast® at high frequency.

NO. OF  
COPIES ORGANIZATION

1 ADMINISTRATOR  
DEFENSE TECHNICAL INFO CTR  
ATTN DTIC OCA  
8725 JOHN J KINGMAN RD  
STE 0944  
FT BELVOIR VA 22060-6218

1 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL CI AI R REC MGMT  
2800 POWDER MILL RD  
ADELPHI MD 20783-1197

1 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL CI LL TECH LIB  
2800 POWDER MILL RD  
ADELPHI MD 20783-1197

1 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL D D SMITH  
2800 POWDER MILL RD  
ADELPHI MD 20783-1197

1 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL SE RL B PIEKARSKI  
2800 POWDER MILL RD  
ADELPHI MD 20783-1197

1 ARDEC  
ATTN AMSTA AR AEC T S LONGO  
PICATINNY ARSENAL NJ  
07806-5000

4 ARDEC  
ATTN AMSTA AR AET A S CHUNG  
M AMORUSO D CARLUCCI  
R COLLET  
PICATINNY ARSENAL NJ  
07806-5000

1 ARDEC  
ATTN AMSTA AR SCF D  
ATTN G ECKSTEIN  
PICATINNY ARSENAL NJ  
07806-5000

1 MCATD ARDEC  
ATTN NIGEL GRAY  
PICATINNY ARSENAL NJ  
07806-5000

NO. OF  
COPIES ORGANIZATION

3 ARDEC  
ATTN AMSTA FSP A V ILLARDI  
R WERKO R SICIGNANO  
PICATINNY ARSENAL NJ  
07806-5000

1 ADAWS ARDEC  
ATTN M MATTICE  
PICATINNY ARSENAL NJ  
07806-5000

1 ARDEC  
ATTN W VOGT  
BLDG 171A  
PICATINNY ARSENAL NJ  
07806-5000

1 ARDEC  
ATTN AMSTA AR FZ L SPRINGER  
PICATINNY ARSENAL NJ  
07806-5000

3 REDSTONE TECHNICAL TEST CTR  
ATTN STERT TE F TD R EPPS  
S HAATAJA K WHIGHAM  
BLDG 7855  
REDSTONE ARSENAL AL 35898-8052

1 AUBURN UNIVERSITY  
ATTN R BARRETT  
211 AEROSPACE ENGINEER ST  
AUBURN UNIV AL 36849-5338

5 JOHNS HOPKINS APP PHYSICS LAB  
ATTN R BENSON H CHARLES JR  
R DENISSEN W DEVEREUX  
D WICKENDEN  
11100 JOHN HOPKINS RD  
LAUREL MD 20723-6099

1 MALLETT TECHNOLOGY  
ATTN M MAHELIC  
14900 SWEITZER LN STE 202  
LAUREL MD 20707-2915

1 BOLL SYSTEMS ASSOC  
ATTN R BODENSCHATZ  
2001 N BEAUREGARD ST STE 800  
ALEXANDRIA VA 22311-1772

2 IDA  
ATTN J FRASIER R SINGER  
1801 N BEAUREGARD ST STE 800  
ALEXANDRIA VA 22311-1772

NO. OF  
COPIES ORGANIZATION

1 DYN CORP  
ATTN B SNOWDEN  
4001 FAIRFAX DR STE 200  
ARLINGTON VA 22203

1 SRS TECHNOLOGIES  
ATTN J SUDDRETH  
3900 FAIRFAX DR  
ARLINGTON VA 22203

1 DARPA  
ATTN B TANG  
3701 FAIRFAX DR  
ARLINGTON VA 22203-1714

1 ALLIANT TECH INC  
ATTN J THALHEIMER  
1911 N FT MEYER DR STE 800  
ARLINGTON VA 22209

1 NATIONS INC  
ATTN R CARPENTER  
12249 SCIENCE DRIVE  
ORLANDO FL 32826

3 STRICOM  
ATTN AMSTI LL R COLANGELO  
M PHILLIPS D SCHNEIDER  
12350 RSCH PARK  
ORLANDO FL 32826-3276

1 NAWC  
ATTN WPNS G BORGES  
521 9TH ST BLDG 311  
POINT MUGU CA 93042-5001

2 NAWC  
ATTN L HOGE CODE 543E00E  
D POWELL CODE 543200E  
521 9TH ST BLDG 311  
POINT MUGU CA 93042-5001

1 NAWC  
ATTN S KUJIRAOKA  
521 9TH ST BLDG 609  
POINT MUGU CA 93042-5001

1 US ARO  
ENG & ENV SCIENCES DIV  
ATTN T DOLIGALSKI  
POB 12211  
RSCH TRIANGLE PK NC 27709

NO. OF  
COPIES ORGANIZATION

2 AEROVIRONMENT INC  
ATTN A ANDRIUKOV M KEENNON  
4685 3H INDUSTRIAL ST  
SIMI VALLEY CA 93063

1 ALLIANT TECHSYSTEMS  
ATTN C CANDLAND  
600 SECOND STREET NE  
HOPKINS MN 55343-8384

2 KOI PRECISION PRODUCTS  
ATTN M CONE W KURTZ  
3975 MCMANN ROAD  
CINCINNATI OH 45245-2395

1 R CHRISTIANSEN  
3370 MIRALOMA AVE  
ANAHEIM CA 92803-3105

1 CREATIVE OPTICS  
ATTN J EBERSOLE  
360 STATE ROUTE 101  
BEDFORD NH 03110-5031

2 DRAPER LABORATORY  
ATTN J ELWELL J SITOMER  
555 TECHNOLOGY SQ  
CAMBRIDGE MA 02139

1 ANALOG DEVICES  
ATTN B SULOUFF  
21 OSBORN STREET  
CAMBRIDGE MA 02139-3556

2 NAWC  
ATTN S GATTIS CODE 54A000D  
S MEYER CODE 543400D  
1 ADMINISTRATION CIRCLE  
CHINA LAKE CA 93555-6001

2 HAIGH-FARR  
ATTN D FARR H FARR  
12 INDUSTRIAL WAY  
SALEM NH 03079

1 PATUXENT RIVER NAS  
ATTN R FAULSTICH  
UNIT 1 47765 RANCH RD  
PAX RIVER MD 20670-1469

2 NSWC/DD  
ATTN J FRAYSSE  
D HAGAN CODE G304  
17320 DAHLGREN ROAD  
DAHLGREN VA 22448-5100

NO. OF  
COPIES ORGANIZATION

1 NSWC/IHDI  
ATTN D GARVICK CODE 40D  
101 STRAUSS AVE  
INDIAN HEAD MD 20640-5035

1 TOMMY HICKS  
8816 CROSSWIND DRIVE  
FORT WORTH TX 76719

1 GARY LEE  
13627 PORTOFINO DRIVE  
DEL MAR CA 92014

1 MACROVISION  
ATTN T MACDONALD  
55 WALKER'S BROOK DR  
READING MA 01867-3297

1 ROBERT MEISENHOLDER  
804 WOBURN ST  
WILMINGTON MA 01887-3462

1 ROBERT MIRACKI  
3500 WEST BALCONES CTR  
AUSTIN TX 78759-5398

1 WL/MNAV  
ATTN G WINCHENBACH  
101 W EGLIN BLVD  
EGLIN AFB FL 32542-6810

1 DAVID PAREKH  
7220 RICHARDSON RD  
SMYRNA GA 30080

2 PRIMEX TECHNOLOGIES  
ATTN J BUZZETT  
R TADDEO  
10101 9TH STREET NORTH  
ST PETERSBURG FL 33716

3 ARROW TECH ASSOC  
ATTN W HATHAWAY  
J WHYTE R WHYTE  
1233 SHELBURNE RD  
SOUTH BURLINGTON VT 05403

1 INTERSECT TECHNOLOGIES INC  
ATTN GEORGE BALL  
2030 E BROADWAY STE 215  
TUCSON AZ 85719

NO. OF  
COPIES ORGANIZATION

1 SUKAMAR CHAKRAVARTHY  
650 HAMPSHIRE ROAD  
WESTLAKE VILLAGE CA  
91361-2501

ABERDEEN PROVING GROUND

2 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL CI LP (TECH LIB)  
BLDG 305 APG AA

2 DIR ATC  
ATTN STEAC TC E K MCMULLEN  
H CUNNINGHAM  
BLDG 400  
APG AA

8 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL WM BC P PLOSTINS  
M BUNDY D LYON  
B GUIDOS T ERLINE  
J SAHU D WEBB  
P WEINACHT  
BLDG 390

27 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL WM BA T BROWN  
F BRANDON T BROSEAU  
L BURKE W CLAY  
J CONDON B DAVIS  
J FAUST R HADDOX  
T HARKINS C HENRY  
D HEPNER M HOLLIS (5 CYS)  
G KATULKA V LEITZKE  
R MCGEE J MCLAUGHLIN  
C MERMEGAN P MULLER  
P PERIGINO A THOMPSON  
S WANSACK R WERT  
BLDG 4600

1 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL WM MA S MCKNIGHT  
BLDG 4600

5 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL WM MB J BENDER  
T BOGETTI L BURTON  
B KASTE W SPURGEON  
BLDG 4600

NO. OF  
COPIES ORGANIZATION

4 DIRECTOR  
US ARMY RSCH LABORATORY  
ATTN AMSRL WM MC P HUANG  
J LASALVIA P PATEL  
J SWAB  
BLDG 4600

NO. OF  
COPIES ORGANIZATION

2 DEFENCE EVAL & RSCH AGENCY  
ATTN R BEATTIE C CROMPTON  
DRA FORT HALSTEAD  
SEVENOAKS  
KENT TN14 7BP  
ENGLAND

INTENTIONALLY LEFT BLANK

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

|  |   |  |                            |   |  |
|--|---|--|----------------------------|---|--|
| 1. AGENCY USE ONLY (Leave blank)   |   | 2. REPORT DATE<br>January 2002                             |                            | 3. REPORT TYPE AND DATES COVERED<br>Final                           |  |
| 4. TITLE AND SUBTITLE<br><br>Polymeric Material Study for the D-Fuze Windshield  |   |  |                            | 5. FUNDING NUMBERS<br><br>PR: 1L162618AH80                          |  |
| 6. AUTHOR(S)<br><br>Hollis, M.S.L. (ARL)   |   |  |                            |   |  |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><br>U.S. Army Research Laboratory<br>Weapons & Materials Research Directorate<br>Aberdeen Proving Ground, MD 21010-5066  |   |  |                            | 8. PERFORMING ORGANIZATION<br>REPORT NUMBER                         |  |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)<br><br>U.S. Army Research Laboratory<br>Weapons & Materials Research Directorate<br>Aberdeen Proving Ground, MD 21010-5066   |   |  |                            | 10. SPONSORING/MONITORING<br>AGENCY REPORT NUMBER<br><br>ARL-MR-525 |  |
| 11. SUPPLEMENTARY NOTES  |   |  |                            |   |  |
| 12a. DISTRIBUTION/AVAILABILITY STATEMENT<br><br>Approved for public release; distribution is unlimited.  |   |  |                            | 12b. DISTRIBUTION CODE  |  |
| 13. ABSTRACT (Maximum 200 words)<br><p>Pursuant to a previous report [1], an effort has been made to continue to find higher performance materials for the design of windshields. A product that the U.S. Army Research Laboratory provides the test and evaluation community is a yawsonde, now termed "diagnostic fuze" or "D-fuze". This device is capable of sensing the inertial environment of a cannon-launched projectile and telemetering the live data to a ground station. In order to telemeter data in flight, the antenna has to radiate through a protective windshield. This windshield is not only transparent to radio frequency radiation but is also a means of ballistic and thermal protection.</p> <p>A recent flight experiment with a prototype artillery projectile revealed a weakness of the nylon 66 windshields to "blow-by<sup>1</sup>" gases. The windshields were designed to survive aero-pressures attributable to Mach 3 launch and flight with a significant safety factor. However, blow-by effects were never considered.</p> <p>A cursory study has been performed on selected extruded bar stock polymers, which are readily available without our having to consult a compounding source, for machining windshields for D-fuzes of various geometries. Ultem<sup>®</sup> 2300 appears to provide the best mechanical, thermal, and electrical properties of the studied polymer materials. However, depending on the thickness of the geometry, a designer may want to reconsider using unfilled Ultem<sup>®</sup> 1000. The cross section of the geometry reduces to a range near 0.03125 inch; there may not be enough glass fiber to reinforce the polyetherimide matrix. Further literature research indicated that the ogive of the M762 fuze is made from injected molded polyetherimide with 30% glass filler.</p> <p><sup>1</sup>Propulsion gases that leak past the projectile's obturator. In addition to the air already being pushed by the launching projectile, these gases increase the total pressure on the windshield.</p> |   |  |                            |   |  |
| 14. SUBJECT TERMS<br><br>polymer      windshield<br>radome   |   |  |                            | 15. NUMBER OF PAGES<br>28   |  |
|  |   |  |                            | 16. PRICE CODE  |  |
| 17. SECURITY CLASSIFICATION<br>OF REPORT<br>Unclassified   | 18. SECURITY CLASSIFICATION<br>OF THIS PAGE<br>Unclassified | 19. SECURITY CLASSIFICATION<br>OF ABSTRACT<br>Unclassified | 20. LIMITATION OF ABSTRACT |   |  |